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TRANSLATION

MUTUAL SOLUBILITY OF COPPER AND MOLYBDENUM AND CERTAIN PROPERTIES OF ALLOYS OF MOLYBDENUM WITH COPPER

By

M. L. Baskin, A. V. Savin, et al.

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UNEDITED ROUGH DRAFT TRANSLATION

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MUTUAL SOLUBILITY OF COPPER AND MOLYBDENUM AND CERTAIN PROPERTIES OF ALLOYS OF MOLYBDENUM WITH COPPER*

M.L. Baskin, A.V. Savin, V.I. Tumanov and Yu.A. Eyduk

(Moscow)

In recent times, Mo-Cu alloys have come into use in various branches of industry. They are widely employed as materials for the manufacture of electrical contacts. Study of the mutual solubility of copper and molybdenum and the physicochemical properties of Mo-Cu alloys (electrical resistance, thermal expansion, and the like) is of important practical value.

TABLE 1

Порошок 1	Насыпной вес, г/см³ 2	Адсорбция паров метанола, мг/г 3	Примечание 4
Молибденовый 5	1.60	0.200	ТУ 4—240—54 7
Медный 6	1.49	0.026	ПМ-2, ГОСТ 4960—49 8

1) Powder; 2) loose weight, g/cm^3; 3) adsorption of methanol vapor, mg/g; 4) remarks; 5) molybdenum; 6) copper; 7) TU 4-240-54; 8) PM-2, GOST 4960-49.

The data available in the literature [1-9] on the Mo-Cu system indicate that copper and molybdenum are mutually insoluble in the entire range of concentrations in both the liquid and the solid states. The subjects of these studies were alloys with a relatively high copper content (10% by weight and more).

In the present study, powder-metallurgical methods were used to prepare Mo-Cu alloys containing 1.5-14% of Cu. The alloys were prepared

by the production process.

The sintering temperature of the molybdenum was 1700°. Alloys of molybdenum with small copper contents (1.5-10% by weight) were sintered at the same temperature, since it was determined by the sintering of the molybdenum phase. Briquettes pressed from the Mo-Cu charge either did not sinter at lower temperatures or remained highly porous. The alloy containing 14% by weight of Cu sintered at 1600°.

The porosity of the resulting alloys, which was determined by the metallographic method, was about 0.6% by volume, and that of the pure molybdenum was about 1% by volume.

In all alloys and in the pure molybdenum, the grains of the molybdenum phase were of practically the same size: 25-30μ in the ground mass. To obtain grains of this size, the molybdenum was sintered two times as long as the alloys.

The characteristics of the starting materials are given in Table 1. The average grain size of the original (molybdenum and copper) powders was 1-2μ.

To prevent contamination of the powders with iron, they were mixed in molybdenum-lined mills. The milling balls were also made from molybdenum. The alloy specimens were sintered in molybdenum boats in a resistance furnace with an open molybdenum heater for 1 hour in a hydrogen atmosphere, while the pure molybdenum specimens were sintered for 2 hours. The heat-treatment conditions were as follows: heating in a hydrogen atmosphere to 950°, holding for 5 hours and quenching in oil at room temperature.

The compositions and specific gravities of the alloys are listed in Table 2.

The phase composition was studied by the methods of x-ray and metallographic analysis.* The x-ray diagrams were recorded in a URS-50 ap-

paratus with Co_{K_a} radiation.

The lattice constant of the molybdenum-base phase was determined for the (310)α line to within ±0.0001 kX, and the copper-base lattice constant to within ±0.001 kX from the (111)α line, since the other lines were not detected.

The resistivities of the alloys were determined by the compensation method at room temperature. Averages of 36 measurements were taken as the results. The maximum error of the determination was ±2%. The deviation from the average value did not exceed 0.3%.

The coefficients of linear expansion of the alloys were determined on a dilatometer with quartz rods and an indicator head in the range from 18 to 400°. The determination was liable to an error of ±2.5%.

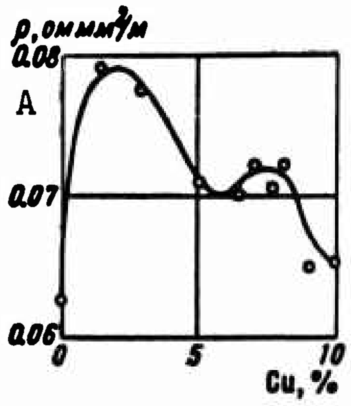

Fig. 1. Resistivity of Mo-Cu alloys as a function of copper content. A) ρ, ohms·mm^2/m.

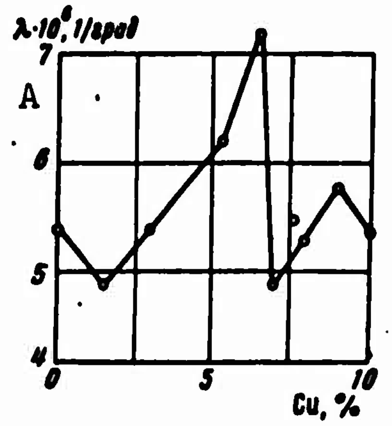

Fig. 2. Linear expansion coefficient of Mo-Cu alloys as a function of copper content. A) $\lambda \cdot 10^6$, deg^{-1}.

To bring out the microstructure, the sections were etched in Murakomi reagent for 2-3 min.

The experimental results are presented in Table 2 and Figs. 1-3.

The data from x-ray structural investigation of the changes in phase composition and lattice constants with changes in copper content in the alloys (Table 2) indicate that about 1.5% by weight of Cu desolves in molybdenum at 950°. These results are in good agreement with

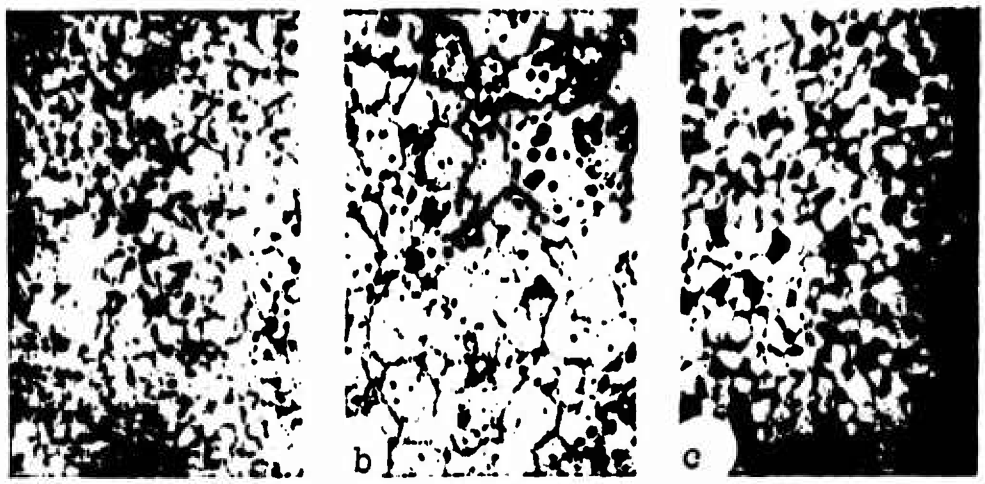

Fig. 3. Microstructure of molybdenum (a) and Mo-Cu alloys containing 1.5 (b) and 14 (c)% of Cu (400 x).

TABLE 2

Structure and Properties of Alloys in Mn-Cu [sic]*

1 •Cu, вес. %	2 d, г/см³	3 ρ×10², ом·мм²/м	4 λ×10⁶ 1/град	5 Фазовый состав**	6 Параметр решетки kX	
					7 Фаза на основе Mo	8 Фаза на основе Cu
0	9.3	6.26	5.4	Mo	3.1403	—
1.5	9.3	7.90	4.7	Mo	3.1400	—
3.0	9.3	7.74	5.4	Mo + Cu	3.1397	3.605
5.0	9.4	7.10	6.2	9 То же	3.1397	3.605
6.5	9.4	7.01	7.2	» »	3.1397	—
7.0	9.8	7.20	4.9	» »	3.1397	—
7.6	9.2	7.06	5.5	» »	3.1397	3.607
8.0	9.2	7.25	5.3	» »	3.1397	—
9.0	9.2	6.36	5.8	» »	3.1397	—
10.0	9.4	—	5.4	» »	3.1397	3.607
14.0	9.1	—	6.6	» »	3.1397	3.606

*Alloys quenched from 950°.
**Mo indicates the molybdenum-base phase and Cu the copper-base phase.

1) Cu, % by weight; 2) d, g/cm^3; 3) $\rho \cdot 10^2$, ohms$\cdot$mm^2/m; 4) $\lambda \cdot 10^6$, deg^{-1}; 5) phase composition**; 6) lattice parameter, kX; 7) Mo-grouned phase; 8) Cu-ground phase; 9) same.

the changes in resistivity and coefficient of linear expansion of the alloys as functions of copper content. The curve of the concentration dependence of resistivity has a distinct maximum at a content of 1.5% by weight of Cu in the alloy (Fig. 1); to this there corresponds a minimum on the curve of linear expansion coefficient as a function of alloy copper content (Fig. 2).

A calculation of resistivity by the refined Rayleigh formula [10], taking specimen porosity and grain dispersion into account on the assumption that the molybdenum and copper are individualized phases in alloys containing 3% by weight of Cu, gives $\rho = 0.0342$ ohms·mm^2/m.

The experimentally obtained value of the resistivity is 0.0774 ohms·mm^2/m. This indicates formation of a solid solution.

The metallographic examinations (Fig. 3) indicate that the alloy containing 1.5% by weight of Cu is a single-phase type and differs in structure from pure molybdenum in having a larger grain size, which may indicate cumulative recrystallization or recrystallization of molybdenum through the liquid copper. Note should be taken of the second maximum from the copper-content curve of the alloys' resistivity (Fig. 1) and the corresponding minimum of the linear-expansion coefficient (Fig. 2) at a copper concentration of 7% by weight in the alloy, corresponding to a slight change in the lattice constant of the copper-base phase (Table 2). It is possible that solutions based on daltonide-type ($CuMo_8$) compounds of copper with molybdenum form in this region.

TABLE 3

Influence of Impurities on Variation of Molybdenum-phase Lattice Constant and Resistivity of Mo-Cu Alloys with Various Copper Contents

1 Примесь, вес. %	3% Cu		5% Cu		8% Cu	
	2 $\rho \cdot 10^2$, ом·мм²/м	a, kX	2 $\rho \times 10^2$, ом·мм²/м	a, kX	2 $\rho \times 10^2$, ом·мм²/м	a, kX
—	7.74	3.1397	7.10	3.1397	7.25	3.1397
0.05% C	8.55	3.1393	7.75	—	7.65	3.1395
0.05% Si	—	—	—	—	8.58	—
0.10% Si	—	—	—	—	9.61	—
0.50% SiO_2	—	—	17.90	3.1375	17.40	—

1) Impurity, % by weight; 2) $\rho \cdot 10^2$, ohms·mm^2/m.

To study the influence of impurities that are of significance in industrial production of Mo-Cu alloys, we prepared a series of alloys

TABLE 4

Influence of Nickel on the Resistivity of an Alloy of Molybdenum with 5 % by Weight of Cu

1 Ni, вес. %	2 $\rho \times 10^2$, $\frac{ом \cdot мм^2}{м}$	1 Ni, вес. %	2 $\rho \times 10^2$, $\frac{ом \cdot мм^2}{м}$
—	7.10	1.0	12.91
0.5	10.31	3.0	14.92
		5.0	15.29

1) Ni, % by weight; 2) $\rho \cdot 10^2$, ohms $\cdot mm^2/m$.

with carbon, silicon and silicon dioxide as impurities. The results obtained on determining the lattice constant of the molybdenum phase and the resistivities of these alloys are given in Table 3. Additives of carbon, silicon and silicon dioxide increase the resistivity and lower the lattice constant of the molybdenum phase (the lattice constant was not determined for the case of the silicon impurity).

The decrease in the lattice constant of the molybdenum phase on solution of copper and carbon can apparently be accounted for in terms of the formation of a substitutional solution. Further, it is known from [11, 12] that a decrease in the molybdenum lattice constant takes place on solution of carbon in molybdenum (up to 0.8% by weight of Cu).

Table 4 presents results from determination of the resistivities of molybdenum alloys with 5% by weight of Cu and various nickel contents. The nickel impurity increases the resistivity of the alloys sharply. Thus, at 5% by weight of Ni, the resistivity of the alloy is increased by a factor of 2 as compared with the alloy not containing nickel.

The hardness of alloys containing 1.57 and 7.65% by weight of Cu was several percent higher than that of the other Mo-Cu alloys, running to 140-146 kg/mm^2 on the Brinell scale; the ultimate tensile strength of these alloys was 35-40 kg/mm^2.

Si, SiO_2 and Cu impurities slightly increased the hardness of the Mo-Cu alloys (to 179 kg/mm^2 Brinell), while their porosities showed virtually no change.

Introduction of nickel into the Mo-Cu alloys resulted in intensified shrinkage during sintering; specimen porosity diminished to, for example, about 0.2% by volume in the alloy with 5% by weight of Ni.

Conclusions. 1. The lattice constants of the individual phases, resistivities and coefficients of linear expansion were determined for Mo-Cu alloys (1.5-14% by weight of Cu) obtained by powder-metallurgical methods at a sintering temperature of 1600-1700°.

2. Data were obtained indicating formation of a solid solution of copper in molybdenum. The solubility of copper in molybdenum at 950° is about 1.5% by weight.

3. The influence of carbon, silicon, silicon dioxide and nickel impurities on certain properties and the structure of the Mo-Cu alloys was established.

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Manuscript Page No.	[Footnotes]
1	L.G. Grigorenko, A.A. Maksimov, and A.A. Cheredinov participated in the experimental work.
2	The x-ray analysis was performed by L.Kh. Pivovarov, and the metallographic analysis by M.N. Nalimova.

Manuscript Page No.	[Transliterated Symbols]
	ТУ = TU = Tekhnicheskiye usloviya = technical specifications
	ПМ = PM = poroshkovaya metallurgiya = powder metallurgy
	ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = = State All-Union Standard